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STRATEGY SERIES

No 6

The Canadian Petrochemicals and Resins Sector

SECTORAL TECHNOLOGY STRATEGY SERIES

NO. 6 THE CANADIAN PETROCHEMICALS AND RESINS SECTOR

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Contents

Highlights v
Background to the Sectoral Technology Strategy Series vi
Commentary on the Sectoral Technology Strategy Series and R&D Targets vii
List of Sectoral Technology Strategy Series Reports ix
Acknowledgements x

Introduction 1

Overview of the Global Petrochemical Sector 2
- The Global Petrochemical Market 2
- Competitiveness 5
- The Global Petrochemical Sector 6
  - Europe 6
  - United States 7
  - Japan 8
  - Eastern Europe 10

R&D and Investment Strategies in the Global Petrochemical Sector 11
- Global Industrial R&D 11
- Factors for Success in R&D 11
- R&D and Future Competitiveness 12
- The Environment: A Major R&D Issue 14

Overview of the Canadian Petrochemical Sector 15
- Development of the Canadian Sector 16
- A Comparison with Union Carbide 16
- Investment and Profits in the Canadian Industry 18
- Analysis by Chemical 18
  - Ethylene 18
  - Polyethylene Resins 19
  - Ethylene Dichloride/Vinyl Chloride Monomer/Polyvinyl Chloride Resins 20
  - Ethylbenzene/Styrene/Polystyrene 20
  - Acrylonitrile Butadiene Styrene Resins 21
  - Butadiene/Synthetic Rubbers 21
  - Ethylene Oxide/Ethylene Glycol 21
  - Polypropylene Resins 22
  - Benzene/Xylene 22
  - Methanol 22
  - MTBE 23

R&D and Technological Competitiveness in the Canadian Petrochemical Sector 24
- Canadian Petrochemical Technology Strategies 24
- Assessing the Canadian Petrochemical R&D Performance 25
- Major Canadian Petrochemical Companies 26
  - Nova Petrochemicals 26
  - Dow Chemical Canada 27
  - Du Pont Canada 28

ICI Canada 28
Esso Chemical Canada 28
Shell Canada Chemical 28
University Petrochemical R&D 29

Opportunities and Growth Strategies for the Canadian Petrochemical Sector 30
Questioning Canada's Commodity Orientation 30
Options for Future Growth 31
More Product Mandates 31
Marketing 31
Environmental Regulation 31
Integrating the Production Cycle 31
The Challenges Ahead 32

Appendix: Framework for Technology Strategies 33

Notes 35

Tables and Figure

Table 1. Top 20 chemical producers (1987) 7
Table 2. U.S. share of world capacity of major petrochemicals (1989) 8
Table 3. U.S. production levels of major petrochemicals (1988-1991) 9
Table 4. R&D spending of some major U.S. chemical companies (1986-1989) 13
Table 5. Major petrochemicals produced in Canada 15
Table 6. Change in export sales of ethane-based commodity petrochemicals (1983-1989) 17
Table 7. Canadian petrochemical industry: fixed capital expenditures and net profit 18
Table 8. Technology strategies of Canadian petrochemical firms 25
Table 9. Major petrochemical producers in Canada 27

Figure 1. Sources of primary petrochemicals 3

Highlights

- Major petrochemical industries exist in Western Europe, North America, and Japan; other oil- and gas-rich countries are developing petrochemical industries as well. Mexico is likely to become a significant competitor.

- Major new competition will probably come from Japan in the 1990s. This competition will likely be based on entirely new investments, use the latest technology, and employ recently developed, low-cost Mexican feedstocks.

- Petrochemicals can be classified as commodities or specialties. The Canadian industry has a heavy concentration in commodity chemicals; it is less well developed in specialty chemicals.

- Competitive factors favouring Canada as a production site for commodity chemicals include low-cost feedstocks (for example, Alberta's natural gas); access to the best available technology, either through licensing or from related "parent" multinationals; low energy costs; and access to international markets, especially the U.S. Midwest.

- During the 1970s, Canadian industry expanded to build an "export" petrochemical business, based on low-cost feedstocks.

- The major domestic Canadian firms are: Nova Petrochemicals; Dow Chemical Canada; Du Pont Canada; CIL/ICI Canada; Esso Chemical Canada; and Shell Canada Chemical. In general, these firms have world-scale facilities and rely on an "adopt and adapt" technology strategy.

- In many integrated multinational companies, it is difficult to distinguish petrochemical research from oil- and gas-refining research generally. Data on R&D are scattered throughout numerous publications and appear in a variety of formats. Although it would have been preferable to use international R&D comparisons based on value-added rather than total-sales figures as a means of normalizing the comparisons, such data were impossible to obtain.

- The environment will undoubtedly become increasingly important as a research and production issue in the petrochemical industry.

- Although Canada's commodity petrochemicals are technologically and economically competitive, they have relatively low profitability. It is the specialty chemicals that offer opportunities in niche areas (pulp and paper, environment) for higher profitability. However, Canada has limited unique product or process technology with which to exploit opportunities in specialty chemicals.

- Although the Canadian petrochemical industry shows great potential for innovation in both process and market applications, the incentive to innovate at present is minimal. But opportunities for long-term pay-offs in specialty chemical production may surface in the future. The key challenge is to develop a more sophisticated integration of the whole production cycle, from raw materials to finished products.

Background to the Sectoral Technology Strategy Series

In the emerging "new" economy of the 1990s, successful high-value businesses in advanced nations are being driven by innovation, propelled by spending on new products and processes. Their business strategies centre increasingly on specialized knowledge and skill in finding the right "fit" between their unique blend of core technologies and particular markets.

Where does Canada stand in this rapidly evolving new environment of changing linkages and relationships? The poor innovative capacity of Canadian industry has long been a concern of the Science Council of Canada, going back to its 1971 report *Innovation in a Cold Climate*. The Council re-emphasized this concern in 1988. It focused its attention on the potential for action at a sectoral level in its statement *A Sectoral Approach to Innovation*. It argued:

> There is growing recognition by industry and government in Canada of the key role played by technology and R&D in domestic and international competition. The Science Council considers that it is primarily the responsibility of industries to raise the degree of domestic technological sophistication and the level of R&D. Nevertheless, governments can help business to sustain long-term competitiveness both by building partnerships with individual firms and by generating consensus on the formulation of innovation strategies for the various industrial sectors. The intent is not for government to tell business what to do, but to facilitate business cooperation in a process of self-help. The process of building consensus on a strategy for a particular sector will involve close and on-going consultation with industries about the current role of technology and R&D in the sector, the opportunities foreseen, and the nature of the sources, stimuli, and forms of technological innovation. Obviously, to be successful, separate innovation strategies will be needed for each sector. The Science Council hopes that the process of building consensus will generate commitment and collective will concerning priorities, areas for cooperation, and agenda for action.

This 1988 statement proved to be an important step in the path that subsequently led the Council to undertake a major Sectoral Technology Strategy project.

In 1989, Industry, Science and Technology Canada, at a time of heightened concern for the state of Canadian competitiveness and serious questioning about the low level of Canada's gross expenditures on research and development as measured against other advanced countries, agreed to provide the main funding for this project. It also stipulated the selection of sectors on which it would like the project to focus.

Each report in this Sectoral Technology Strategy Series draws in part upon analyses commissioned by the Science Council of Canada from contractors, designed to reveal the key dynamics driving technological innovation in the sector and influencing company technology strategies. Each report has also benefited considerably from the comments and advice submitted by the many external reviewers from business, universities, and government, who are recognized in the Acknowledgements.

Commentary on the Sectoral Technology Strategy Series and R&D Targets

The Sectoral Technology Strategy Series has analysed 15 Canadian sectors. On the basis of this experience, the Science Council of Canada makes the following points with regard to Canadian R&D performance and the issue of setting sectoral R&D targets.

- Canadian firms, when grouped by sectors, generally perform much less R&D than their trade competitors. Using the indicator of R&D as a percentage of sales, Canadian firms undertake R&D at a rate about one-third to one-half the rate of their leading international sectoral competitors. The notable exception among those sectors analysed in telecommunications.

- In some product lines or specific technologies certain absolute threshold levels of R&D and capital investment must be reached if the effort is to be considered to have a chance of making a commercial payback. High thresholds are apparent in some parts of sectors such as telecommunications (central office switches), automotive parts ("Tier 1" supplier status), oil and gas (reformulated gasoline standards by refineries), and electronics (integrated circuit foundry). Such absolute thresholds cannot be clearly expressed as a percentage of sales.

- The reasons for the lower level of R&D spending by firms in most of the 15 Canadian sectors are: choice of business and technology strategy (which, in part, leave Canadian companies as essentially non-participants in many higher value-adding segments); the relatively small size of Canadian firms; the high absolute thresholds of R&D expenditure required to be a meaningful player, especially for innovative technology strategies; and the degree of foreign ownership of Canadian firms (especially important in the case of the automotive vehicles and parts sectors).

- The lack of R&D relative to other countries affects Canadian competitiveness, but it is only one of many factors, such as capital and labour costs, quality design, good marketing, and management, that interact to affect overall competitiveness. Nevertheless, the contribution of R&D, or more precisely, technology-based innovation, is becoming more pronounced throughout the global economy and Canada continues to fall behind. The low level of R&D is especially detrimental to the capacity of Canadian resource-based sectors to compete with higher-value, differentiated products, leaving them vulnerable to adverse shifts in costs beyond their control, such as a higher exchange rate.

- Major potential does exist for Canadian industry to make additional R&D investments. However, fulfilling this potential depends heavily on the vision and capability of management to make strategic use of technology, to speed the firms' innovation process, to work more closely with suppliers and "demanding customers" all the way to the end of the product chain, and to build core capabilities in incremental innovation and R&D. Canadian firms have not yet fully grasped the implications of the emerging new "lean enterprise" or "agile producer" strategy. To follow this new strategy involves seeking to offer maximum value to customers. It requires integrating the skills base of a knowledgeable workforce with flexible management structures that stimulate cooperative initiatives within and between firms to match customer needs.

- The dominant technology strategies being followed by Canadian firms in these sectors are of adopt and adapt. Innovation technology strategies are not very extensive (telecommunications is again an exception) and hardly any firms focus on breakthrough strategies to enhance competitiveness. Overall, these 15 sectors show little attempt at diversification out of existing product lines as opposed to making such products more efficiently.

- Governments can set sectoral R&D targets in the hope of stimulating enhanced industrial performance, shifts in business strategy, and greater commitment by the private sector to R&D. However, private sector R&D is only meaningfully undertaken in conjunction with a full complement of associated private and public sector actions ranging from improved design and production to finance and marketing. Doing more R&D will not be productive unless linked to a broader corporate technology strategy that is carefully designed to support the firm's business objectives. Otherwise, the corporation cannot, and will not, marshal the complementary investments required to reap the benefits of the R&D. It is the firm that must commit R&D resources.

- Setting sectoral R&D targets becomes more difficult as the boundaries between sectors are breaking down, through technological advances, regulatory change, and firm restructuring. Larger and more diversified firms that dominate modern industrial R&D perform R&D that might be allocated to any of several sectors. Examples include the textiles and materials R&D performed by large Japanese steel firms, the electronics R&D by automotive-vehicle firms, and the software R&D by telecommunications firms. Canadian governments have quite correctly encouraged higher levels of industrial R&D in Canada. In view of the rapid pace of scientific advances and technological change, plus the role of system interdependencies and synergies between technologies, setting R&D targets does not appear to be a task warranting the intensive effort, cooperation, and, ultimately, commitment that would be required by federal and provincial governments and private sector organizations.

List of Sectoral Technology Strategy Series Reports

No. 1 The Canadian Telecommunications Sector
No. 2 The Canadian Automotive-Parts Sector
No. 3 The Canadian Iron and Steel Sector
No. 4 The Canadian Automotive-Vehicle Sector
No. 5 The Canadian Oil and Gas Sector
No. 6 The Canadian Petrochemicals and Resins Sector
No. 7 The Canadian Banking Sector
No. 8 The Canadian Nonferrous-Metals Sector
No. 9 The Canadian Forest-Products Sector
No. 10 The Canadian Machinery Sector
No. 11 The Canadian Food and Beverage Sector
No. 12 The Canadian Electric-Power Sector
No. 13 The Canadian Consulting-Engineering Sector
No. 14 The Canadian Electronics Sector
No. 15 The Canadian Computer Software and Services Sector

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Introduction

With its access to abundant, competitively priced feedstocks and its generally good access to markets and leading-edge technology, one might expect the Canadian petrochemical sector to be highly successful. But is it? As a sector it is dominated both domestically and globally by multinational firms that, except in the case of specialty chemicals, compete primarily on a price basis. During the past decade, the sector has also undergone significant global structural change.

The main objectives of this report are to review the technology strategies of the leading petrochemical firms and to compare Canada's R&D performance with that of its main trade competitors, outlining the major reasons for any differences and how those differences affect Canada's competitiveness.

Overview of the Global Petrochemical Sector

Petrochemicals are organic chemicals derived from crude oil and natural gas. In Canada, about 90 per cent of all oil and gas produced is used as fuel for transportation or heating. The remaining 10 per cent (comprising 4 per cent of crude oil production and 25 per cent of natural gas production) is converted into petrochemical feedstocks, which include natural gas liquids, liquefied petroleum gas, naphtha, and gas oil. These feedstocks are converted into final products, which include gasoline, fuel oils, lubricating oils, greases, waxes, asphalts, or primary petrochemicals such as ethylene, propylene, butadiene, benzene, toluene, xylenes, and methanol (see Figure 1).

Primary petrochemicals are upgraded to intermediate products such as styrene, ethylene dichloride, propylene, and vinyl chloride monomer (VCM) and, further, into large-volume plastic resins such as polyethylene, polystyrene, polypropylene, nylon, and acrylics. From the plastic resins are derived synthetic fibres, synthetic rubbers, paints, and plastic products.

In North America, natural gas liquids constitute the major feedstocks for petrochemicals. In Western Europe and Japan, the primary source of feedstocks is naphtha. With the advent of North Sea natural gas, natural gas liquids are increasingly being used as feedstocks in Western Europe.

The Global Petrochemical Market

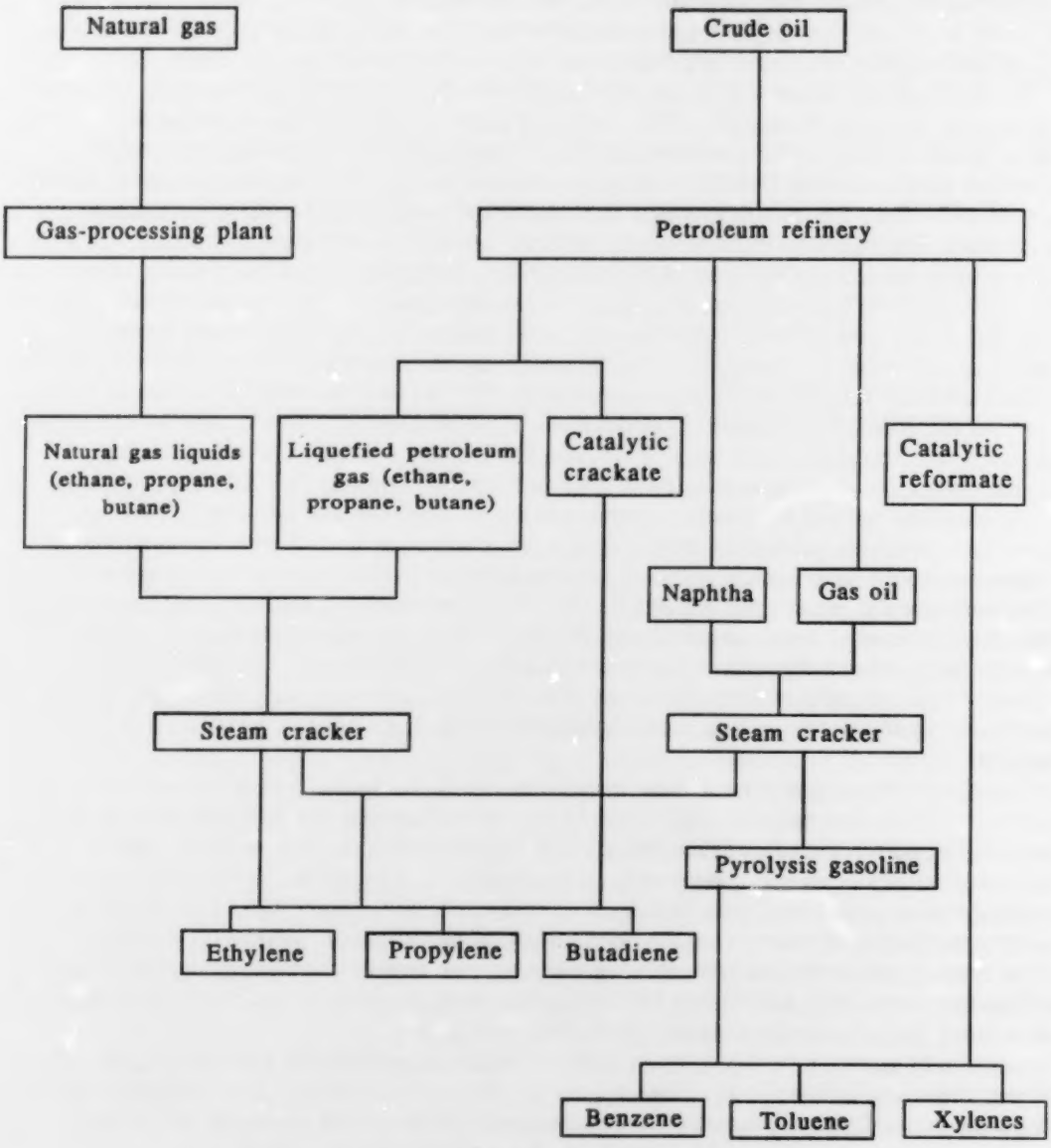
Petrochemicals are generally classified as either commodity or specialty chemicals. *Commodity chemicals*, which include the primary petrochemical feedstocks and bulk intermediates, are sold on the basis of physical or chemical specifications, such as purity, colour, boiling or freezing point, and density. If a chemical meets the specifications, its actual production site (company or country) is usually immaterial. In general, competition is based on price, although if shortages are envisioned, the promise of a guaranteed supply might well influence the buyer's decision.

Specialty chemicals, which include some plastics and resins, are sold on the basis of the functions they perform, as well as their reliability in performing those functions, rather than on physical or chemical properties. Price is less important with specialty chemicals: not only will customers buy from a company having the chemical that satisfies their needs, they will often work with a company to develop a new chemical or formulation for a specific need. Specialty chemicals command higher prices than commodity chemicals and, therefore, return greater profits per unit of sales. In turn, however, specialty chemicals are never sold in the same volume as commodity chemicals.

Historically, the United States, Western Europe, and Japan have been the world's three major petrochemical-producing areas. All three areas had a strong domestic market base for their products; they also accounted for most of the world's trade in petrochemical products. With the growth of petrochemical industries in oil- and gas-rich developing countries, such as Saudi Arabia, this situation is now changing.

During the 1950s and 1960s, the petrochemical industry had a double-digit annual growth rate worldwide. This performance can be attributed to two factors: the continuously declining price of petrochemical feedstocks, and the entry of chemicals into new markets. The post-war period saw the emergence of large, efficient processing plants that incorporated the latest technological developments emanating from the R&D laboratories of the major companies. However, the industry's growth attracted many new entrants. The result was overcapacity and oversupply, falling product prices, and lower profit margins. In the petrochemical sector, the critical economic factor has always been economies of scale; that is, the bigger the plant, the cheaper the unit output. Technology, however, could not always keep up with the producers' demands for lower costs. Occasionally problems

Figure 1. Sources of primary petrochemicals



Source: SRI International

emerged. For example, valves had to be redesigned, not just made larger; storage tanks could get bigger, but they needed carefully designed baffles to keep stored liquids stable.

Business strategies were inevitably linked to the need to exploit economies of scale, that is, to maintain large output volumes and continuity of operations. Producers were forced into defending their market share. Indeed, any firm that could not retain its market share soon lost opportunities to maximize economies of scale and eventually ran the risk of being put out of business. Profit margins were cut to the bone, and even beyond, just to keep the huge new plants working. By 1972, margins were so low that the pace of capacity expansions had to slow down to reduce oversupply.

The petrochemical sector was greatly affected by the oil-price increases in the early 1970s and 1980s. During the oil crisis of the early 1970s, feedstock prices almost doubled, becoming the dominant competitive factor in the petrochemical sector. Some independent chemical companies without assured supplies of raw materials from parent oil companies had to stop manufacturing certain chemicals. In 1974, fears that prices would go even higher led to inventory building by feedstock purchasers, which, together with increased revenues from higher-priced chemical products, temporarily improved the financial position for petrochemical companies. Riding an artificial wave of optimism, petrochemical companies began to expand capacity once again, especially those owned by oil companies, which saw production of petrochemicals as a means of adding value to their products. These moves again resulted in overcapacity, falling prices, and lower profits.

The market for petrochemicals depends on markets for the final products; these, in turn, depend on prevailing economic conditions. Major markets for petrochemical products include housing materials, household appliances, furniture and fixtures, automobiles, and tires and tubes. During economic recessions, however, as seen in 1982-1983 and currently (starting in 1990), housing markets decline. The attendant demand for plastics, synthetic fibres for carpeting and furnishings, coatings, major household appliances, foam for furniture, and so on, declines as well. A recession-associated slowdown in automobile sales occurs, resulting in cutbacks in automobile production and reduced demand for such items as plastics for vehicle interiors, foams and textiles for seating, and synthetic rubbers for tires. The recent structural changes in the North American automobile markets, which resulted in declining sales of domestic vehicles and increased sales of imports, also affected the downstream plastics and resins markets. However, this effect was somewhat alleviated by the foreign companies' building of assembly plants in North America and their sourcing of supplies from local manufacturers.

Although there has always been some international trade in chemicals, it is only since the oil crisis in the early 1970s that petrochemical plants have been built specifically to export most of their production. At that point, many less-developed oil- and gas-rich countries, such as Saudi Arabia, Malaysia, and Mexico, saw an opportunity to develop petrochemical industries, thereby adding value to their energy resources and increasing their level of industrialization. Incentives offered by these countries attracted foreign investment for the development of petrochemical production facilities.[1] Many of the ensuing plants resulted from joint ventures between foreign chemical producers (mainly U.S. and Japanese companies) and oil-rich Middle Eastern countries (such as Saudi Arabia, through the Saudi Arabian Basic Industries Corporation; Kuwait; and Iran).

Extensive investments were also made in the Canadian petrochemicals sector during the late 1970s, as a means of exploiting Canada's rich oil and gas resources and of meeting anticipated export market demands for feedstocks. Because of its discovery of large quantities of natural gas in the 1970s, New Zealand was also able at this time to develop a petrochemical industry.

A trend of the past decade has been to build petrochemical plants in countries with no major natural resources and only a small domestic market. Witness the recently erected plant in Singapore. Many people in the industry believe that Singapore, situated as it is in the growing market of the Far East, will be a significant chemical manufacturing centre by the turn of the century.

Another possible development site for petrochemicals is Mexico. Three forces favour the growth of that country's petrochemical industry. First, Mexico is likely to have, overall, the lowest-cost feedstocks in the North American market. Second, Mexico may soon become part of a North American free trade zone. Third, Japanese companies may well launch new investments in petrochemicals there, based on new technology.

The oil crisis of the early 1980s resulted in a major rationalization of the petrochemical industry: inefficient plants were shut and some companies dropped product lines. But the recovery of the late 1980s, with its increased company profits, gave rise to another major capacity expansion. That, in turn, was succeeded by yet another period of instability, occasioned by the recent war in the Persian Gulf.

Because the performance of the petrochemical and resins sector is closely tied to oil and gas prices, it is not easy to forecast what might happen to the industry over the next decade. Futurists have made predictions based on various scenarios, taking into account world economic growth, the production and pricing policies of the Organization of Petroleum-Exporting Countries, changes in end-user markets, new technology developments, and the probability of fresh oil and gas discoveries. Energy consultants Purvin and Gertz of Houston, Texas, and Hycarb Engineering of Calgary, Alberta, suggest that oil prices will stay low (U.S.$15-18 per barrel) throughout the 1990s. Their forecasts do, however, suggest real price increases after the year 2000 (see Science Council of Canada Sectoral Technology Strategy Series, No. 5: *The Canadian Oil and Gas Sector*). Such increases in oil prices would, in turn, raise petrochemical feedstock prices and possibly delay future expansion plans.

Competitiveness

To be competitive — in terms of both positioning products and maintaining markets — the petrochemical industry needs low-cost feedstocks and the best technology available. Appropriate business and technology strategies will depend on the market dynamics of the specific chemicals.

In the area of commodity petrochemicals, a competitive raw materials base is usually required before investment in a plant can proceed. The market is fiercely competitive. Indeed, even a quarter of a cent per pound — essentially a trivial margin — can mean the difference between profit and loss. Because price advantages of raw materials tend to erode over time, production research can become a major factor in maintaining a competitive edge. For example, Union Carbide claims that its research on process catalysts and plant design netted the company the most efficient plants in the world for producing ethylene glycol and justified investment in a new plant in Alberta.

Global supply and distribution networks also constitute key competitive factors in the commodity chemicals sector. Simply put, these factors mean feeding the output from a company's plants directly into a global supply network and then marketing the product using a worldwide sales force. Examples of this strategy can be seen with styrene production at Shell, polyethylene and glycol at Dow Chemical, polyethylene at Exxon, and polypropylene at Himont. Naturally, the role of economies of scale in commodity-processing plants is important in driving this marketing operation.

In the downstream plastics and resins market of the petrochemical sector, product customization, or the tailoring of products to fit a particular market, constitutes a major competitive strategy. Research is required to find optimal process conditions, as well as catalysts and additives for the various grades of such products. Considerable work is also necessary to produce resins with specific characteristics for end-use applications. These resins are expected to command higher prices to recoup their R&D investment. With such specialization, producers are moving their resins into the bailiwick of the specialty chemicals.

As a company accumulates experience, production efficiencies can be realized; the base price of the product will accordingly decrease. In addition, the knowledge gained through operating production plants in various locations can be used to set up and run new plants, thereby helping to keep down both production costs and the price of commodity chemicals.

The Global Petrochemical Sector

The largest petrochemical companies are located in Western Europe and the United States, although, in the past two years, some Japanese companies have begun to penetrate the "top 20" category. This Japanese growth is the result of acquisitions and joint ventures with European, Middle Eastern, and North American companies.

Table 1 lists the world's major petrochemical producers and their sales in 1987. The restructuring of the European petrochemical industry in the late 1980s, plus the expansion of Japanese companies outside Japan, will have caused a reordering and introduced new companies to the group, including Mitsubishi Chemicals, Asahi Chemical, and Sumitomo Chemicals. It should be noted that Table 1 does not necessarily indicate the exact ranking of the companies in terms of petrochemical sales. Several of the top 10 companies have substantial non-chemical businesses and also produce chemicals that fall outside the petrochemical categories. In fact, most of the companies listed in Table 1 also have chemical businesses other than petrochemicals and resins, including pharmaceuticals, fertilizers, pesticides, and inorganics. Unfortunately, a breakdown of sales in the various categories is unavailable. Caution is therefore advised when making international comparisons. It should also be noted that the Canadian chemicals industry is heavily oriented to commodity petrochemicals and polymers; Canada thus plays a less important role in other areas, such as specialty chemicals.

Europe

During the early 1980s, a combination of higher oil prices, overproduction, and the effects of the recession sent the European chemical industry into a decline. Industry losses in 1982 were in the order of $7 million per day. A major rationalization and a three-phase restructuring of the industry, outlined below, ensued.[2]

Phase 1. Simple retrenchment was effected to reduce capacity. The result was an improvement in the efficiency of the plants. Some plants were closed; certain businesses were disposed of entirely. Goals changed as well. Instead of trying to produce a wide range of products, the chemical companies sought to become leaders in a few specific products.

Phase 2. Nationwide restructurings were instigated, with companies collaborating to redistribute their assets. The objective of these moves — accomplished through joint ventures, mergers, and exchanges — was to increase market share and force smaller competitors out of business.

Phase 3. Internationalization became a top priority. Whereas prior to the 1980s, most European chemical companies concentrated on serving domestic markets, in the 1980s, European producers began to realize about 20 per cent of their sales in North America. (Most of the chemicals currently sold in North America, however, are still locally produced.) Today, most European producers also manufacture and sell goods in the four major European markets: Germany, Britain, Italy, and France. Buy-outs, mergers, and joint ventures have been used to expand into international markets.

Few of the European chemical firms are linked to oil companies. One of the advantages of such independence is that the chemical companies are more market- than feedstock-driven. Most of the

feedstock for European chemical companies comes from the Middle East, where prices are subject to fluctuations. The restructuring to produce fewer products means that the fluctuations in demand for, and prices of, the products have a greater effect on the sales and profits of the chemical companies than was once the case.

Table 1. Top 20 chemical producers (1987)

Company	Country	1987 sales (U.S.$ billions)
BASF	West Germany	25.6
Bayer	West Germany	23.6
Hoechst	West Germany	23.5
ICI	United Kingdom	21.0
Du Pont	United States	17.6
Dow Chemical	United States	13.4
Ciba-Geigy	Switzerland	12.4
Montedison	Italy	11.9
Shell	Holland, United Kingdom	11.7
Rhone-Poulenc	France	10.6
AKZO	Holland	8.8
Monsanto	United States	7.6
Exxon	United States	7.2
Sandoz	Switzerland	7.1
Union Carbide	United States	6.9
Solvay	Belgium	6.8
Roche Sapac	Switzerland	6.1
EniChem	Italy	5.3
Norsk Hydro	Norway	5.3
DSM	Holland	5.1

Source: "Shake, heat, squeaky-pop," *The Economist*, 16 July 1988, 68-69.

Growth in demand is predicted to slow in 1991 as governments try to control inflation. Indeed, the predicted slowdown has already delayed expansion plans.[3]

United States

The United States has one of the most advanced petrochemical industries in the world. A number of factors — the availability of low-cost feedstocks, access to technology, and a well-developed infrastructure, as well as a large domestic market — have provided the necessary support for the industry's growth. By 1989, the United States accounted for approximately one-third of the world's capacity for certain of the major petrochemicals (Table 2).

During the early 1980s, increased competition from other petrochemical-producing countries, overcapacity, sluggish demand (particularly in commodity chemicals), and high feedstock prices combined to force the U.S. petrochemical industry to restructure. As had happened in Europe during

Table 2. U.S. share of world capacity of major petrochemicals (1989)

Petrochemical	World capacity share (%)
Ethylene	30
Propylene	33
Benzene	31
Methanol	23
Poly-Xylene	31

Source: SRI International, "Overview of U.S. Petrochemical Industry, Technology, and R&D Developments," contract report prepared for Science Council of Canada, 1990 (unpublished), 11.

this period, petrochemical companies sold or closed unprofitable operations, shut inefficient plants, and initiated joint projects with other companies to reduce the risk of business failure. In extreme cases, some companies abandoned commodity chemical production altogether, seeking more recession-resistant businesses, such as specialty chemicals and nondurable consumer products.

By 1986, these efforts had paid off, and a better balance between supply and demand was achieved. However, by 1987, with the strong economy and favourable crude oil prices, demand had begun to outpace supply. Also, in certain sectors, the capacity reduction of the early 1980s had been so great that, by 1987-88, shortages were occurring. By 1989, however, demand had again lessened, although the U.S. industry remained dynamic.[4]

In 1990, the production of chemicals and synthetic materials declined, in response to reduced demand in several key markets, such as construction and automobiles. Thus, although several new plants are now ready to come on stream, current production is only about 81 per cent of the country's 1989 capacity. In addition, although the increased prices of crude oil and natural gas — they rose temporarily because of the Gulf crisis — were passed on to customers, a sharp fall has occurred in the earnings of commodity chemical producers. All in all, the uncertainty after the Gulf crisis, coupled with the recession, has meant a less than optimistic outlook for U.S. chemical companies in the early 1990s.

In fact, production of most major chemicals in the United States is predicted to decline over the short term by 7 to 8 per cent from 1990 levels.[5] Production levels for primary petrochemicals over the past three years, as well as predictions for 1991, are shown in Table 3.

Japan

The Japanese petrochemical industry has also undergone restructuring as part of that country's Industrial Structural Improvement Program. As a result, the commodity petrochemical business now has a higher degree of capacity utilization. The industry has also been rationalized to achieve economies of scale. Compared with their U.S. and European competitors, however, the Japanese companies are smaller and tend to have a broader product spectrum. While this approach may be an

Table 3. U.S. production levels of major petrochemicals (1988-1991) (million tonnes)

Chemical	1988	1989	1900	1991*
Ethylene	16.87	15.85	16.33	15.65
Propylene	9.63	9.08	9.75	9.25
Butadiene	1.44	1.40	1.36	1.22
Benzene†	1 608	1 585	1 600	1 400
Xylenes	2.98	2.87	2.76	2.63

Source: "World Chemical Outlook," *Chemical and Engineering News*, 10 December 1990, 28.

* Estimated
† Millions of gallons

advantage — smaller, less bureaucratic companies can be more innovative and achieve specialized technical excellence — too broad a spectrum of products with smaller production capacity can also mean that variety is achieved at the expense of economies of scale in production.

Few Japanese producers have production facilities outside Japan at present. Nevertheless, in the past few years, some have entered into offshore joint ventures with Middle Eastern countries, ventures that may signify an important new trend for the Japanese industry.

The Japanese chemical companies compete against those in the United States and Europe. They also face increased competitive pressures from new petrochemical companies in Taiwan and Korea. The Japanese purchase their crude oil and natural gas in U.S. dollars. In the 1980s, the yen was strong compared to the U.S. dollar; hence, the Japanese companies' costs for raw materials declined. But because the international chemical trade is also conducted in dollars, the cost of Japanese chemicals was higher on the export markets. For Japan, with its status as a net importer of chemical products since 1982, the strong yen has worked to the advantage of its industry as a whole.

A major problem for the Japanese petrochemical industry has been the decision of Japanese automobile companies to build plants in North America and Europe and to purchase plastics from North American or European chemicals companies. Offsetting this development is the research being conducted in Japan on advanced polymers and composites for use in vehicles. Not only do these materials already have a number of aerospace applications, but all-plastic automobiles could become a reality in the next decade. Indeed, Japanese companies have been applying for patents for advanced polymers at a greater rate than other countries. Opportunities to apply the processing technology to the manufacture of composite structures are emerging as well.

One potential scenario has the Japanese industry investing in Mexico, with sales objectives in the North American market. Mexican oil fields are the most recently developed on the North American continent and hence may well offer the lowest-cost feedstocks. A North American free trade agreement would allow easy export to both Canada and the United States from Mexico. Clearly, if the auto industry worldwide were to use plastic composites in much greater quantities, as some Japanese auto companies are doing, the market would be huge.

Although Japan's chemical industry has been growing in the past few years, it remains dependent on imported naphtha, most of which comes from the Middle East, for 90 per cent of its requirements. But the war in the Persian Gulf resulted in high naphtha prices. In October 1990, for

example, the cost of naphtha increased by $100 a tonne. Domestic naphtha, which is produced from imported crude oil, also increased in price. Although some of the price increases can be passed on to customers, increased prices may be difficult to maintain if demand starts to drop.[6] Nonetheless, in 1990, Japanese chemical companies were planning important capacity expansions in ethylene and other major petrochemicals.

Eastern Europe

In 1990, in the aftermath of the political changes in Europe, chemical companies worldwide were optimistic about the opportunities to participate in the development and modernization of the Eastern European chemical industry. Like that of Western Europe, the chemical industry in Eastern Europe has a long tradition, dating back to the late 1800s. For most East European countries, the source of crude oil and natural gas for their petrochemical feedstocks has been the former Soviet Union. The only other East European country with indigenous oil and gas reserves is Romania.[7]

Today, that optimism has been tempered by the realization that pollution damage is worse than originally feared and that cleanup costs could be several hundred billion deutschemarks. Prospective partnerships, or purchases of plants, have been stalled by the issue of pollution liability as well. In addition, plants in East European countries are outdated and energy intensive. Thus, although Eastern Europe represents a huge market for items such as plastics and textiles, Western companies at present are in no rush to expand their interests into the area. As for the more distant future, if the former Soviet Union's large gas reserves could be made available at competitive prices, that region might become a major producer.

R&D and Investment Strategies in the Global Petrochemical Sector

Global Industrial R&D

The modern chemical industry had its origins in Germany in the latter part of the 19th century in the development of synthetic dyes. Before that time, chemical research had been directed mainly at isolating and identifying chemical elements, and at understanding their structure. The research in Germany not only reproduced natural substances, but also created new substances not found in nature.

Although the industry grew slowly during the latter part of the 1800s, a period of rapid expansion succeeded World War I, bringing with it the development of the first synthetic polymers and fibres. Even more rapid expansion took place after World War II. By that time, almost every chemical company had R&D laboratories, and companies were spending approximately 5 per cent of sales on R&D, synthesizing new molecules and developing new technology. Profit margins were in the order of 15 per cent.

By the mid-1960s, profitability in the industry was on a downswing. The rate of development of potentially useful new monomers and polymers had declined, and the level of R&D as a percentage of sales was slipping as well. The decline in the R&D intensity of the petrochemical sector during the 1970s has been attributed to technological maturity.[8] Process technology worldwide was roughly comparable, and the sector had become chiefly a commodity business. With the large oil companies' entry into the marketplace, competition increased and lower profit margins resulted, thereby discouraging major R&D expenditures with long-term and uncertain payoffs. Yet despite this, the chemical sector was still R&D-intensive, compared with other mature sectors. Indeed, in 1979, the chemical industries in the member countries of the Organization for Economic Co-operation and Development (OECD) spent more than U.S.$13 billion on R&D, the equivalent of approximately 3 per cent of sales, or one-fifth of all industrial R&D.[9]

At the same time, cheap feedstocks and large plants allowed companies to shift their R&D efforts so as to maximize production and return on investments and to diversify outside the chemical business. These moves had the effect of reducing innovation in the industry. Baily and Chakrabarti[10] note a dramatic reduction in the average number of chemical product innovations in the United States during the 1970s. As a whole, by relying on licensing and relatively free technology mobility, the petrochemical sector moved closer to an "adopt and adapt" technology strategy (see Appendix for definition of technology strategy classes).

One of the results of the 1973 oil crisis was a shift, especially in Europe and Japan, in the focus of chemical companies' R&D away from basic research, which might lead to new products, to process improvements and energy efficiency. The overcapacity at the end of the 1970s, as well as the oil crisis of the early 1980s, resulted in another change in research direction: many major companies turned to the development of specialty chemicals and to biotechnology. Again, R&D as a percentage of sales began to rise, and, by 1984, it ranged from 2.5 to 6.0 per cent for the larger companies.

Factors for Success in R&D

One of the most comprehensive studies concerning successful industrial innovations, Project SAPPHO, was undertaken by the Science Policy Research Unit (SPRU) at the University of Sussex.[11] The project, which measured roughly 100 characteristics of some 40 pairs of innovations (40 successes and

40 failures), initially concentrated on two branches of the manufacturing industry: chemicals and scientific instruments. (It was later extended to include other industries.) The researchers identified the following conditions as the most important for systematically discriminating between success and failure in chemical industrial innovation:[12]

- an understanding of user needs;
- the integration of R&D, production, and marketing functions;
- linkages with an external science and technology network;
- concentrated, high-quality R&D;
- the participation of powerful, experienced, senior business innovators; and
- basic research activity within the enterprise.

The chemical industry differs from the other industries examined by SPRU in that it is relatively economically concentrated and, in most countries, dominated by a few large firms. Its process innovations require both laboratory research and expensive pilot-plant work, which in turn require extensive collaboration with design engineering and construction firms. In fact, some innovations have been made by plant contractors. Over a long period of time, a few companies have dominated in radical innovations. The SAPPHO researchers attributed this domination by a few to "technological accumulation" — the development, within a firm, of strong traditions in research and innovation in key, specialized areas. Many of the innovations were incremental, but some were radical and based on new scientific foundations (a similar pattern has been found in other science-based industries[13]).

Freeman, director of SPRU, attributes the recent changes in the chemical industry to a change in the techno-economic paradigm, based on information and communication technology.[14] He claims that the decline in the number of innovations in the chemical industry was associated with technological developments that had affected many other industries. For instance, electronic instrumentation allowed for process control; computer technology permitted the integration of such functions as design, R&D, and production; and communications technology linked together the various sites of activity. Each technology change allowed for greater flexibility. Freeman adds that the rise of industries such as electronics, which requires specialty products rather than commodity chemicals, also profoundly affected the chemical industry. These changes, he says, will require new management techniques to integrate R&D, production, marketing, and work organization.

Freeman also suggests that the Japanese style of innovation management seems well adapted to the new techno-economic paradigm, which places the Japanese chemical industry in an advantageous position. He notes, however, that the European and U.S. chemical industries are also changing rapidly. Their strengths in basic research as well as their university linkages place them in a strong position to face any Japanese challenge.

Another major issue in chemical R&D is the division of effort between product and process experimentation. Generally speaking, process technology is readily available in the industry, while product technology is not. Because product technology serves as the basis for the more profitable specialty chemicals market, it is much more carefully guarded by the individual companies. In the petrochemical sector, a high proportion of R&D given over to product innovation may well be a promising indicator of long-term profitability.

R&D and Future Competitiveness

The U.S. chemical and allied products industry accounted for a total R&D spending of about U.S.$10.9 billion in 1989. This represents about 12 per cent of total U.S. industrial R&D.[15]

Additional government and university R&D expenditures of about U.S.$1.3 billion brought total 1989 chemical R&D to about U.S.$12.2 billion.

Table 4 shows the chemical R&D spending of some of the larger U.S. companies from 1986 to 1989. However, there is a problem in interpreting this table, because although some of these companies' R&D is in petrochemicals, the majority tends to be in specialty fields such as electronics, drugs, herbicides, insecticides, fertilizers, and so on. Indeed, SRI International estimated that R&D spending in chemicals proper in 1989 was only U.S.$6.5 billion.[16] Nevertheless, Table 4 does show that R&D spending overall rose during the 1980s.

Table 4. R&D spending of some major U.S. chemical companies (1986-1989) (U.S.$ millions)

Company	1986	1987	1988	1989	R&D/sales ratio 1989 (%)
Du Pont	1 156	1 223	1 319	1 387	3.9
Dow Chemical	605	670	772	873	5.0
Monsanto	605	670	648	598	6.9
Union Carbide	148	159	159	181	2.1

Source: SRI International, "Overview of U.S. Petrochemical Industry, Technology, and R&D Developments," contract report prepared for Science Council of Canada, 1990 (unpublished), 63-67.

Just what impact the Japanese chemical industry's R&D will have on the world market, particularly on the North American industry's competitiveness, is unknown at present. It could, however, represent an important new competitive factor. Although in the past the Japanese chemical industry has not had a major impact on either the North American or the global markets, recent anecdotal evidence[17] indicates that Japanese R&D spending in the chemical industry is rising rapidly and may now have reached the equivalent of 60 to 70 per cent of its capital investment rate. Given that chemicals in general, and petrochemicals in particular, are highly capital-intensive, this level of spending represents a substantial R&D effort for Japan — somewhere in the range of 6 to 12 per cent of sales. Contrast these figures with the overall R&D to sales ratio figures for major U.S. companies, shown in Table 4, which range from 2.1 to 6.9 per cent.

The great danger to Canadian and U.S. firms in any major expansion of Japanese technological innovation is clear. That is, the whole of the North American petrochemical industry — and the United States is as vulnerable here as Canada — could be overtaken by Japan's new technology in much the same way as was the North American iron and steel industry. (See Science Council of Canada Sectoral Technology Strategy Series, No. 3: *The Canadian Iron and Steel Sector.*) Indeed, the Japanese approach to petrochemical research could be very similar to that country's strategy in the iron and steel sector. Briefly, Japanese iron and steel companies were driven to improve their products by the requirements of an end-product industry — the automotive industry — and research developed backward along the supply chain, creating innovations along the way. In other words, the Japanese automobile companies became the Japanese iron and steel industry's "most demanding customers," at which point the needs of the end-product forced significant research by suppliers. For example, in the early 1970s, Japanese cars exported to North America were definitely not superior to North American automobiles in terms of rust resistance. But, 20 years later, it is a completely different story. Indeed, in

many industries today, Japan's commitment to technology and long-term research — with the clear objective of gaining market share and eventually dominating the market — is a formidable force. Will petrochemicals be next on the list?

Consider, for example, the demands of Honda on its plastics suppliers. The Honda CRX comes equipped with unusual, relatively flat, plastic body panels. Normally, exterior body panels are curved to assist in maintaining rigidity. But Honda kept pressuring its suppliers to provide comparable strength with minimal curvature. And the result? Not only has the CRX gained interior space relative to its external size with this technology, but, of course, it cannot rust.

All in all, a Japanese challenge cannot be ruled out, although just what its significance will be in the next few years is debatable. Look out, however, for new large-scale Japanese investment in Mexico. Such investment will serve as a leading indicator that Japanese firms are confident that they have the technology to gain a significant petrochemical market share.

The Environment: A Major R&D Issue

During the last decade, the contribution of the chemical industry to environmental pollution has become a major issue in industrialized countries. The ensuing legislation has attempted to force chemical companies not only to clean up their operations, but also to find materials to replace some persistent toxic chemicals, such as polychlorinated biphenyls (PCBs) and dioxins. Substitutes are also being sought for other chemicals that have been found to damage the environment, such as chlorofluorocarbons (CFCs), which deplete the ozone layer.

The pollutants from petrochemical complexes are many, including reaction by-products; reactor wash water; water used as a medium in surge-pressure emulsions; cooling water; condensates; and drainage water from production, storage, and transfer areas. Air purification systems and catalyst regeneration cause difficulties as well. The very complexity of the wastewaters challenges companies to find ways of extracting pollutants to meet the required emission standards. One U.S. plant that manufactures over 900 organic chemical products (75 per cent of which fall into the U.S. Environmental Protection Agency category of organic chemicals, plastics, and synthetic fibres) had to characterize all 200 of its wastewater streams and develop optimum source control and treatment processes for each, in order to meet the stringent pretreatment standards recently introduced in the United States for this category of chemicals.[18]

In addition to air and water pollution, the industry faces problems regarding the disposal of solid wastes, such as sludges from reactor vessels, that contain chemicals banned from landfill sites. Many chemical companies are involved in costly cleanup operations to remove hazardous chemicals from former landfill and dump sites. The chemical companies are also directing considerable R&D effort to developing treatment processes for chemical wastes and finding replacement, or substitute, materials and closed-loop production processes. Research into biodegradable plastics and methods of recycling solid plastics is also part of the pollution reduction effort.

All in all, the petrochemical industry now recognizes that it has a "cradle-to-grave" responsibility for the chemicals it produces and is taking steps to deal with the issues. In the United States, for example, the Industry Cooperative for Ozone Layer Protection has been established to work with the Environmental Protection Agency to reduce, and eventually eliminate, the use of CFCs as solvents. Several Canadian companies are members of the Cooperative.

Overview of the Canadian Petrochemical Sector

Canada's petrochemical industry has expanded over the past two decades to exploit the country's abundant and cheap natural gas and oil. Canada's three major producing areas are Alberta, southwestern Ontario (Sarnia), and Montréal East. The bulk of the output from the Western Canadian plants is exported to the United States, with excess going to Asia. The plants in Eastern Canada serve Ontario's industrial belt and export their excess production mainly to the United States, although some does go to Europe. In 1989 the Canadian petrochemical industry generated $6.7 billion in revenues, $3.1 billion of which was in export revenues. Overall, the industry had a trade surplus of over $800 million.[19]

The Canadian petrochemical industry produces raw materials and resins for the plastics industry, as well as feedstocks for the specialty chemicals sector. Over 25 major petrochemicals and resins are produced for either domestic consumption or export (Table 5).

Table 5. Major petrochemicals produced in Canada

Ethylene	Benzene
Toluene/Xylene	Propylene
Ethylene dichloride	Vinyl chloride
Polyvinyl chloride	Polyethylene
Ethylbenzene	Styrene
Nylon resins	Cumene
Phenol	Acetone
Ethanol	Polypropylene
Ethylene oxide	Ethylene glycol
Propylene oxide	Propylene glycol
Ethylene amines	Ethanol amines
Butadiene	Butadiene rubber
SB latex	Methanol

Source: Law, Sigurdson and Associates, "Analysis of Technology Adoption and R&D Activity among Canadian Petrochemical Firms," contract report prepared for Science Council of Canada, 1990 (unpublished), II-3.

Alberta, with its production from natural gas of ethylene-based petrochemicals, ammonia-based fertilizers, and methanol, accounts for more than half of Canada's petrochemical production capacity. Ontario companies, which use crude oil fractions and some liquefied petroleum gases to produce propylene, ethylene derivatives, aromatics, and C_4's and natural gas to produce ammonia-based fertilizers and explosives, account for 35 per cent of Canada's capacity. Crude oil fractions form the basis of Quebec's petrochemical industry, which accounts for roughly 9 per cent of Canada's overall capacity. Somewhat further down the scale comes British Columbia: its production of methanol and ammonia-based products from natural gas constitutes about 2.6 per cent of Canada's total capacity. Like British Columbia, Manitoba has a very small production capacity. Its production is limited to ammonia-based fertilizers.

The Canadian synthetic resins industry is made up of 86 establishments that produce a variety of resins and compounds. The plastics products industry, as these firms' major customer, consumes over half the sector's output; other client industries include the adhesives, forest products, metals, wire and cable, paint, petroleum products, and chemical specialties. Canada has a net deficit trade position in synthetic resins, with the United States accounting for the bulk of Canada's import/export trade.

Clearly, Canada has feedstock advantages and has developed considerable capability in the petrochemical and resins secto.. It has opportunities to expand that capability by working with customers in a downstream-integration strategy that emphasizes the earning of product mandates from parent multinationals and focuses on product differentiation.

Development of the Canadian Sector

In the 1970s, North American chemical producers, wary of investing in the Middle East, planned huge investments in chemical plants in Western Canada. However, the federal government's National Energy Plan — founded on the assumption that world energy prices would continue to rise — rendered the Canadian industry noncompetitive. The taxes on Albertan oil — a petroleum consumption charge, and a Canadian special ownership charge — resulted in a rise in the costs of Canadian feedstocks. By the end of 1982, the price of ethylene in Alberta had increased to 25 cents per pound, compared with 20 cents per pound on the U.S. Gulf coast. This resulted in approximately 75 per cent of those planned expansion projects, worth about $7.5 billion, being abandoned or shelved. But in the latter part of the 1980s, partly because of the uncertainties vis-à-vis the Middle East and partly because of a more favourable economic climate, petrochemical capacity again expanded in Western Canada.

A major competitive strength of the Canadian petrochemical industry is its supply of available raw materials, particularly natural gas in Western Canada. Much of Alberta's petrochemical production is based on the extraction of ethane, propane, and butane from natural gas. The ethane is converted to ethylene and various ethylene derivatives, while the butane and propane are shipped as natural gas liquids to Eastern Canada to serve as feedstock for ethylene plants. From Canadian crude oil, the other source of raw materials, are extracted naphtha, gas oil, benzene, toluene, and xylene. The availability and relatively low cost of Canadian feedstocks have rendered Canada particularly suitable for the production of commodity chemicals. In general, Canadian petrochemical production is commodity- rather than specialty-oriented.

During the 1980s, the focus of the Canadian petrochemical industry changed from that of a small-scale supplier for the domestic market to that of a large-scale supplier for the export (U.S.) market. Indeed, much of the output of the large, efficient plants in Alberta, built to take advantage of the cheap ethane feedstock, is directed to export markets. Table 6 traces the growth in exports of certain ethane-based cc.mmodities.

Except for the polyvinyl chloride resins, these are spectacular growth figures, especially for such mature commodity products.

A Comparison with Union Carbide

By way of putting Canada's petrochemical output and activities into perspective, let us examine the Chemicals and Plastics Group of Union Carbide (the largest of that company's three divisions). The Chemicals and Plastics Group operates on a global basis, fully integrating technology development,

Table 6. Change in export sales of ethane-based commodity petrochemicals (1983-1989) (C$ millions)

	1983	1989	% change
Polyethylene	161.6	687.7	+425
Ethylene dichloride	152.3	227.3	+149
Vinyl chloride monomer	58.2	121.1	+208
Polyvinyl chloride resins	54.0	13.6	- 75
Styrene	79.9	473.7	+592
Ethylene glycol	133.9	342.3	+256

Source: Law, Sigurdson and Associates, "Analysis of Technology Adoption and R&D Activities among Canadian Petrochemical Firms," contract report prepared for Science Council of Canada, 1990 (unpublished), II-3.

marketing, and production skills. This group had worldwide sales in 1989 of U.S.$5.6 billion, or just under the Canadian petrochemical industry's total sales of C$6.7 billion. It also employed 17 000 people around the world, as compared to the slightly more than 14 500 people working in Canada's entire petrochemical industry.[20] In effect, the size of one plastics and chemicals group of a major chemical firm roughly equals the size of the whole of Canada's petrochemical industry.

This comparison is noteworthy for several reasons. First, it shows that the Canadian industry is, in absolute terms, really quite small by global standards. After all, Union Carbide is not one of the largest petrochemical producers. Second, it shows that the Canadian industry uses fewer employees to generate slightly higher revenues. By the traditional measure of labour productivity, this suggests that the Canadian industry is economically efficient. But, third, this efficiency reflects the heavy concentration by the Canadian sector on the commodity side of the petrochemical business, for large-scale production of commodities means that fewer employees are required for any given output. Although efficient, Canada's petrochemical industry is limited by this commodity orientation, particularly in terms of upside profit potential; specialty chemicals might have been expected to provide better returns. In fact, this last point may help to explain the relatively small size of the Canadian industry. It seems that, although the investment in commodity production that could be justified was indeed made, the "hurdle" or threshold rate of return that any given company expects was sufficiently high to discourage additional growth. In effect, growth in the Canadian industry has only been possible, given the need for maximum economies of scale for commodity chemicals production, when the market has expanded enough to offer realistic pay-offs from fresh investment.

Two other points can be drawn from the Union Carbide comparison. First, the Canadian petrochemical industry has a limited global marketing capability. Second, the Canadian petrochemical industry is not a full product line sector. Lacking a "total systems capability" of its own, it essentially exists as a rationalized segment of a North American industry.

Investment and Profits in the Canadian Industry

The Canadian petrochemical industry, although very cyclical, has been profitable enough to justify increased capital investment (see Table 7).

Table 7. Canadian petrochemical industry: fixed capital expenditures and net profit (C$ millions)

	1985	1986	1987	1988	1989	1990*	1991*	1992*
Fixed capital expenditures	220	280	254	322	459	700	707	643
Net profit before taxes, after interest and write-offs	(899)†	(135)†	918	2 191	1 114	‡	‡	‡

Source: Canadian Chemical Producers' Association, *Annual Report 1990* (Ottawa), 19-20.

* Forecasts in 1989 dollars
† Net losses
‡ Forecasts are unavailable

Analysis by Chemical

Ethylene

The production of ethylene, the feedstock for over 70 per cent of Canadian petrochemicals, also generates propylene, butadiene, butylenes, and some aromatics, including benzene.[21] Ethylene is used to feed local plants producing ethylene derivatives, particularly polyethylene, ethylbenzene, ethylene oxide, and ethylene dichloride. Canadian plants, which tend to be "world-scale" — capacity of about 1 billion pounds or 450 kilotonnes annually (kt/a) — employ the latest, or one-generation-old, technology. Canada's major ethylene producers are Alberta Gas Ethylene, Joffre, Alberta, with a 1520-kt/a-capacity plant; Nova Petrochemicals, Sarnia, with a 600-kt/a-capacity plant; and Esso Chemical, Sarnia, and Petromont Inc., Montréal, each with plants of approximately 250-kt/a capacity. In addition, Dow Chemical is currently building a 500-kt/a-capacity plant at Fort Saskatchewan, Alberta, scheduled to come on stream in 1994.

Ethylene production technology is obtained from petrochemical or engineering companies. Dow Chemical and Exxon have their own ethylene plant technology, and the Alberta Gas Ethylene plant in Joffre was engineered and built by Dow Chemical.

The bulk of ethylene production in North America uses steam cracking of hydrocarbons, a process with three basic steps: pyrolysis and cooling; compression and acid gas removal; and cryogenic cooling and product separation. A mature process, it has changed little since its development some 40 years ago. However, various improvements have been made over the years. These include the installation of short-residence furnaces to optimize yield; better heat integration to reduce energy consumption; computer control and instrumentation to reduce costs and improve quality control; and various environmental protection measures to provide early detection of leaks and equipment failure.

Although technologies exist to produce ethylene from alternative feedstocks (such as methanol, crude oil, residual fuel oil, and methane), efforts to commercialize these alternatives will depend on how well they compete with existing feedstocks. The intensity of research in these areas fluctuates according to the long-term forecasts for pricing and the availability of crude oil and natural gas liquids.

Polyethylene Resins

Ethylene also serves as the feedstock for polyethylene plastics and resins. Several production processes are used, depending on the density of the polyethylene. Low-density polyethylene is produced by high-pressure processes in which the pure ethylene is polymerized with a peroxide initiator, solidified by cooling, and put through a pelletizing extruder. The original process, developed by Imperial Chemical Industries Limited in the late 1950s, was widely licensed. Since then, most of the original licensees have developed their own proprietary technology, based on modifications of the process.

Linear low-density polyethylene is produced by either a gas-phase or a solution-phase process. In the gas-phase process, ethylene gas and a comonomer are polymerized in a fluidized bed reactor, in the presence of a catalyst, to form a granular polymer. The gas-phase processes of Union Carbide and BP differ chiefly in terms of the copolymer and catalyst used. In the solution-phase process, ethylene is polymerized with a comonomer to form a polymer that is also dissolved in the reaction solvent. Dow Chemical and Du Pont both have solution-phase processes.

High-density polyethylene can be produced by gas-phase, solution-phase, or slurry-phase processes. In the latter, ethylene is polymerized to form solid polymer particles suspended in a hydrocarbon diluent.

These basic processes are all economically competitive and in current commercial use. To a great extent, the products of all three processes compete directly against one another. Each process, however, has certain attributes that permit the production of a unique range of more specialized products.

Catalyst development acts as the primary driver of technology research in high-density polyethylenes. Manufacturers continue to improve their product offerings, developing novel grades of resins so they can compete effectively in existing markets and expand into new applications. The trend toward product differentiation encourages the development of new catalysts that allow precise control of molecular properties.

In 1988, world consumption of polyethylene resins topped 27.7 million tonnes. Forecasters predict an average growth rate of 5.4 per cent in consumption over the next few years, to reach a market of 39.3 million tonnes by 1995.[22] In the late 1980s, the major growth in consumption was centred in the Pacific Rim region; China emerged as an important consumer and importer of polyethylene resins.

Canada is a net exporter of polyethylene resins. The present Canadian polyethylene production capacity of 1580 kt/a represents a rise of 360 kt/a since 1985 — an increase attributable largely to innovations in catalyst technology that boosted effective capacity. In 1989, production of polyethylene was in the order of 1336 kt/a, almost half of which was exported. In effect, it was the heavy investment in new plant technology during the 1980s that caused polyethylene to become an important petrochemical in Canada. Further expansion is planned at certain plants.

The major Canadian producers of polyethylene resins are currently Dow Chemical Canada, Du Pont Canada, Esso Chemical Canada, Nova Corporation, and Petromont. Plant capacities range from 130 to 400 kt/a. The Du Pont plant in Sarnia uses linear technology developed at its research labs in Kingston. This technology, which enables the production of low-, medium-, and high-density polyethylene in one reactor, has been licensed worldwide. The Union Carbide "Unipol" process, which features low capital costs and a wide range of catalysts, permits both low- and high-density resins to

be produced in the same reactor. Unipol technology is used at the Nova plants in Joffre and Sarnia, as well as at the Esso plant in Sarnia. Dow Chemical's "Dowlex" process, which produces low-density resins, is used at Fort Saskatchewan.

Although some process and in-reactor modification work is conducted in Canada — Du Pont Canada, for instance, is still active in this type of work — it tends to be fairly limited. In fact, most of the potential for innovation in the polyethylene resin area in Canada lies in product modification: the adaptation of resins for various specific uses.

Ethylene Dichloride/Vinyl Chloride Monomer/Polyvinyl Chloride Resins

Ethylene dichloride (EDC) serves as an intermediate in the production of vinyl chloride monomer (VCM). In North America, the main processes used to produce VCM are *chlorination*, which entails the catalytic reaction of ethylene with chlorine gas, and *oxychlorination*, which uses hydrogen chloride as the source of the chlorine. Acetylene can also be employed as the raw material for VCM. In many plants, EDC is not isolated before conversion to vinyl chloride.

Because EDC production provides a way of using excess chlorine, it is generally tied to the chloralkali industry. During the 1980s, Canadian EDC exports increased to such a degree that, by 1989, almost one-third of production was being exported. Asia has become an increasingly important market for Canadian EDC exports. By 1989, most of Canada's VCM exports — they amounted, in 1989, to almost one-quarter of Canada's total VCM production of 449.5 kt — were headed for the United States. Dow Chemical Canada is the only Canadian producer of these two chemicals.

Polyvinyl chloride (PVC) is produced by the polymerization of a liquid VCM by suspension, emulsion, bulk, or solution polymerization. The molecular weight distribution of the final product — of key importance to the processing characteristics of the resin — is influenced substantially by the reaction temperature used, as well as by the concentration and type of initiators (for example, peroxides, persulphates). The trend in these batch processes has been toward larger reactors.

Polyvinyl chloride is produced in Canada by Esso Chemical and B.F. Goodrich. The latter, the largest PVC producer in North America, is currently integrating its three Canadian plants into its continental supply network. The Esso plant in Canada houses the only Exxon PVC plant.

The potential for innovation in this area lies in developing PVC compounds for different markets. Various fillers and plasticizers can be used to change the properties of the resin.

Ethylbenzene/Styrene/Polystyrene

Ethylbenzene is produced by alkylation of ethylene with benzene in either the vapour or liquid phase. The vapour-phase process offers distinct advantages over that of the liquid phase: its reaction mixture is heterogeneous and noncorrosive; aqueous waste treatment facilities are not required; and the heat produced by the reaction can be recovered for use.

In North America, the catalytic dehydrogenation of ethylbenzene constitutes the major process used to produce styrene, although styrene is also obtained as a coproduct in the production of propylene oxide. Briefly, the process entails the oxidation of ethylbenzene to its hydroperoxide, which is then catalytically reacted with propylene to produce propylene oxide and methyl phenyl carbinol; the latter is then dehydrated to styrene.

Polystyrene is obtained through the free-radical polymerization of the styrene monomer.

The production of ethylbenzene and styrene is usually integrated, and more than two-thirds of the annual Canadian production of styrene (699 kt) is exported. Canada's three styrene producers are Dow Chemical, Nova Corporation, and Shell Canada.

Nova and Dow also produce polystyrene resins, using some of their styrene production as feedstock. A few smaller polystyrene producers are in operation as well. Canadian-produced

polystyrene is mainly used for domestic purposes, although some is exported to the northern United States.

The major potential for innovation in polystyrene markets can be found in application technology, especially that pertaining to injection moulding. Other potential opportunities lie in the recycling technology.

Acrylonitrile Butadiene Styrene Resins

The polymerization of acrylonitrile, butadiene, and styrene produces acrylonitrile butadiene styrene (ABS) resins, materials characterized by good heat and chemical resistance, as well as gloss and rigidity. Varying the amounts of these basic materials will produce ABS polymers with different properties, for use in auto parts, appliances, drain pipes, and various consumer products. The ABS resins are suitable for injection-moulded applications.

The total Canadian production capacity for ABS resins is 65 kt/a. Both General Electric Canada and Monsanto Canada — the two Canadian producers of ABS resins — obtained their technology from their parent companies. Most R&D activity, which is conducted in the United States, focuses on developing ABS compounds for different applications and developing injection-moulding processes. American researchers are also trying to develop higher-performance "engineering resins." Law, Sigurdson and Associates believes there is little potential for innovation in the Canadian plants.[23]

Butadiene/Synthetic Rubbers

Included in this category are nitrile and butadiene rubbers. Having pioneered the technology in this area during World War II, Polysar built an international business in Canada, the United States, and Europe. Recently, the Polysar rubber business in North America and Europe was sold to Bayer AG of West Germany. Bayer says it will continue R&D activities in Sarnia to support the North American business. Both Dow Chemical and BASF produce synthetic rubbers as well. The BASF technology was developed in part by Polysar, but BASF made modifications after purchasing the plant in the 1980s. The Dow technology came from Dow's parent firm in the United States.

Polysar continues to conduct research into rubber technology, but the product is in a mature stage and the potential for innovation limited. At this point, more R&D opportunities lie in developing products, such as coatings and bindings for the pulp and paper industry.

Ethylene Oxide/Ethylene Glycol

Ethylene oxide is produced either by direct oxidation of ethylene with oxygen or air, or by reacting ethylene with hypochlorous acid to give ethylene chlorohydrin, which is then treated with lime to form the oxide. Although the latter process is more efficient, it consumes large quantities of chlorine; thus from both an ecological and an economic standpoint, it is less attractive than direct oxidation. Ethylene oxide serves as a raw material for surfactants and as a feedstock for ethylene glycol.

Ethylene glycol, used in the manufacture of polyester fibres and as an antifreeze and de-icing fluid, is produced by the noncatalytic liquid-phase hydration of ethylene oxide. Its coproducts (equivalent to about 10 per cent of total output) include diethylene glycol, triethylene glycol, and higher glycols. Companies generally try to maximize the yields of ethylene glycol because the current process is energy-intensive. Companies in the United States and elsewhere are investigating lower-energy processes.

At their Alberta plants, both Dow Chemical and Union Carbide produce glycol, mainly for export to the United States and Asia. Union Carbide's Quebec plant serves Eastern Canadian markets. Both these companies have limited corporate product mandates. Union Carbide Canada specializes in de-icing technology, and Dow Chemical conducts R&D on automobile-engine coolant applications.

Polypropylene Resins

In North America, propylene is obtained either from the steam cracking of hydrocarbons (crude oil or natural gas) or from recovery-from-petroleum operations. Recent changes in the catalytic-cracking process used to produce high-octane gasoline have increased the propylene yield.

Polypropylene is produced by polymerization of the propylene monomer in the presence of Ziegler-Natta catalyst systems, using either a slurry, gas-phase, or solution process. Most advances in polypropylene production have come about as the result of developments in superactive, and highly selective, catalyst systems that eliminate the need to remove catalyst residues and atactic polymer from the final product. The catalysts — typically designated as HY/HS (high yield/high selectivity) catalysts — have been developed by a number of chemical companies.

Polypropylene resins produced in Canada are used in the automotive, appliance, and packaging industries. Two of the three companies with leading positions in polypropylene plant technology, namely, Shell and Himont/Enimont, have built plants in Canada; Mitsui, the third company, has adopted a strategy of licensing its process technology.

The potential for innovation in polypropylene lies in adapting the resin for different market applications. However, with most research being done by the parent companies, there is little potential for innovative work in Canada.

Benzene/Xylene

Both benzene and xylene are derived from crude oil. Benzene is used as a feedstock for solvents as well as in styrene and cumene production, while xylene is used as a feedstock for solvents and in the manufacture of nylon. Benzene can be extracted from catalytic reformate and pyrolysis gasoline; xylenes are isolated from mixed xylene streams via crystallization, or continuous selective adsorption in the liquid phase, using molecular sieves. A number of companies offer technologies for the various processes.

Benzene and xylene are both produced in Eastern Canada, in the Sarnia and Montréal regions. Six benzene plants, with a total capacity of 697 kt/a, are in operation. There are two xylene plants, with a total capacity of 340 kt/a. Because the solvents business is mature technically and declining because of environmental pressures, there is little potential for innovation.

Methanol

Methanol derived from natural gas is manufactured commercially by reacting pressurized synthesis gas in the presence of a catalyst. It is used in the production of formaldehyde, as a de-icing and dewatering agent, as well as in motor fuel. Canada's methanol production capacity of 1840 kt/a, from two plants in Alberta and one in British Columbia, makes Canada a major producer. The volume of methanol exports to the U.S. and Asian markets has grown substantially in the past five years, with approximately 90 per cent of Canada's total production leaving the country. Further important opportunities in methanol production for motor fuel have emerged in Canada as a result of the research carried out by Ford Motor Co. in Oakville and the tightening of emissions standards under way in certain parts of North America, most notably California. (See Science Council of Canada Sectoral Technology Strategy Series, No. 4: *The Canadian Automotive-Vehicle Sector*.)

Methanol is an oxygenated fuel; that is, it contains its own oxygen atoms. In practice, this oxygenation appears to promote more complete combustions and, hence, cleaner exhaust emissions. Methanol's advantage is that it has a high octane rating and does not promote photosynthetized smog. Accordingly, it has potential as an extender, or substitute, for premium unleaded gasoline. By using methanol, the compression ratios of automotive engines can be raised, which allows more efficient operation — a highly desirable phenomenon in light of modern, high-performance engines and the growing need for a cleaner environment. But methanol has its drawbacks: it has a lower overall energy

content than gasoline (that is, fewer miles per gallon are obtained using methanol); it is corrosive; and, in cold weather, it is subject to "phase separation" in the presence of water. These problems appear to be manageable, however.

MTBE

Methyl-tertiary-butyl-ether (MTBE) is the major new ingredient in so-called reformulated gasoline (the high-octane, high-performance gasoline that lacks tetra-ethyl-lead). Like methanol, MTBE is an oxygenated fuel.

The blending of MTBE into gasoline is apparently a critical force in the promotion of process upgrading at North American refineries. Also, the fuel represents an interesting example of the potential, and need, for R&D in even so basic a commodity as gasoline. Although gasoline is not normally viewed as a petrochemical and, by and large, lies outside the scope of this report, the point is that even basic processes in oil refining and chemical production can undergo major changes. (For a more complete technical discussion of MTBE, see Science Council of Canada Sectoral Technology Strategy Series, No. 5: *The Canadian Oil and Gas Sector*.)

Canada is well placed to produce MTBE, largely because of Alberta's natural gas for feedstock. A world-scale facility is under construction in Western Canada.

R&D and Technological Competitiveness in the Canadian Petrochemical Sector

In part because many petrochemical companies in Canada are subsidiaries of multinationals, and in part because of the ready availability of technology for licensing, Canadian petrochemical companies have tended to use the latest technology available at the time of plant construction and to incorporate process improvements as they become available. Similarly, technology developed in Canada can be made available through the parent organization to other parts of the corporation or, through licensing, to other companies. But technical support for the Canadian plants has usually come through each firm's R&D activities in Canada, although multinationals can call upon their parent organization if necessary. In effect, Canadian-owned companies license technology when feasible and have the freedom to search for the best available technology. In a typical illustration of the role of R&D in an "adopt and adapt" technology strategy (see Appendix), the R&D capabilities of Canadian petrochemical companies are geared, in general, to ensuring that the firms keep up to date with the latest global technological developments.

A Statistics Canada survey of the Canadian chemical industry indicates that Canadian chemical companies' R&D, as a percentage of their sales, is less than 1 per cent for the "rubber and plastics" category (which includes most petrochemicals).[24] For the "other chemicals" category (which includes specialty inorganic chemicals and some petrochemicals), the figure is slightly more than 1 per cent of sales. From these data, it appears that R&D in petrochemicals in Canada accounts for slightly less than 1 per cent of sales. However, defining what constitutes R&D is always a difficult exercise. Another survey of major petrochemical producers in Canada, done for the Science Council in 1990 by Law, Sigurdson and Associates, estimates that then-current spending on R&D and technical support among the companies surveyed was in the region of $120 million.[25] Such expenditures represent approximately 1.8 per cent of total 1989 Canadian petrochemical sales. (This survey covered the major producers in Canada; many of the smaller companies do little or no R&D.)

It may be worthwhile comparing the latter R&D level with the capital investment level of Canadian petrochemical companies. Capital investment has fluctuated considerably over the last few years, but it appears to be roughly $500 million annually (Table 7 shows a 1989 figure of $459 million). The R&D level would accordingly represent 26 per cent of capital investment in 1989. If, as noted earlier, Japanese industry is really spending 60 to 70 per cent of its capital investment on R&D, then Canada may well be falling behind. Even the differences in technological strategies that underlie the production of commodity chemicals, as opposed to specialty chemicals, cannot explain this massive difference.

It might be instructive to obtain similar comparative figures for the U.S. petrochemical sector. Even if U.S. R&D is relatively twice as great as that of Canada, it would likely still be inferior to that of the Japanese industry. Thus, the U.S. industry also could conceivably be in danger of falling behind Japan's.

Canadian Petrochemical Technology Strategies

A review of the technology strategies of the majority of the petrochemical companies in Canada shows that most are variants of the adopt and adapt strategy (Table 8). Most R&D activities in Canada take place at the development end of the spectrum — in process modifications, product applications, and product development. This results from the commodity-oriented structure of the industry, as well as the ease with which technology is licensed or acquired from parent firms. Innovation in the

petrochemical industry tends to involve working with customers in developing applications for products and in customizing products and processes.

Table 8. Technology strategies of Canadian petrochemical firms

	Process (%)	Product (%)
Adopt and Adapt	90	70
Innovation	10	30
Breakthrough	—	—

Source: Law, Sigurdson and Associates, "Analysis of Technology Adoption and R&D Activity among Canadian Petrochemical Firms," contract report prepared for Science Council of Canada, 1990 (unpublished), I-10.

Law, Sigurdson and Associates suggests that one of the major reasons for low levels of R&D investment in Canada may be the ownership structure of the petrochemical industry. Foreign-owned companies acquire product and process technology from parent companies, or through licensing from major international companies; they therefore have no real incentive to be innovative. In fact, according to Law, Sigurdson and Associates, Canadian petrochemical companies pay about $50 million per year in royalty and related fees — a large figure, equivalent to 41 per cent of total R&D expenditures. Very few sectors show such a high proportion of licensing and royalty expenses.

It can also be argued that the main reason for low levels of R&D in the group of Canadian companies studied is that these firms are operating businesses in areas where standard technologies are readily available for modest royalties. Many Canadian companies have adopted a business strategy that focuses on commodity markets, which involves upgrading raw materials and exporting chemical feedstocks. Such a strategy provides less opportunity for innovation.

Law, Sigurdson and Associates identifies six companies as conducting process research work in the production of plastic resins in Canada. Development work — which involves the customizing of resins, or the optimizing of the resin process for the customer's production process — is an important aspect of the technical support provided to customers. Indeed, technical and product development support for plastic resin and rubber producers in Canada amounts to between $77 and $91 million annually.

Law, Sigurdson and Associates also found that several foreign-owned subsidiaries in Canada have mandates to conduct product and process R&D work in specific areas. These mandates not only tend to foster innovation, but also enable the companies to "market" the innovation throughout the company and to build up technical resources and expertise to solve market and process problems.

Finally, the thrust in basic petrochemical R&D in Canada over the past few years has been toward process improvements, to achieve greater output. This work has meant the development of new catalysts, plus other technical improvements.

Assessing the Canadian Petrochemical R&D Performance

It may be worth pursuing, once again, the analogy with Union Carbide. Union Carbide's chemical R&D spending in 1989 was U.S.$181 million, or approximately 2.1 per cent of the firm's total sales

(Table 4). In absolute terms, this figure is about 50 per cent greater than that for the Canadian petrochemical industry. It may be somewhat misleading, however, owing to the different mix of products. Union Carbide has a higher proportion of specialty chemicals, which biases upward its R&D spending — as one industry executive put it, "Apples need to be compared with apples, not oranges." Nevertheless, the comparison with Union Carbide at least raises the question of whether Canadian R&D spending is too low, even if data limitations prevent correct normalizing for product mix.

Many industry representatives suggest that a better index of Canadian R&D competitive performance would be a ratio of all the petrochemical firms' R&D spending to their value-added. Commodity chemicals have relatively high input costs (that is, in terms of the contribution of feedstock cost to final output price) and, being commodities, compete on price; margins therefore tend to be thin. Accordingly, the value-added for commodity chemicals is less than that for specialties. Unfortunately, it is not easy to obtain comparable value-added data on an international basis.

It is a judgement call as to whether the Canadian industry is matching its competitors — at least the U.S. industry — in R&D spending on a comparable product-mix basis. Yet the similarity of the sales to R&D ratio between the Canadian industry and a representative multinational organization, Union Carbide, suggests that Canada may be performing a reasonable amount of R&D when product mix is taken into account.

The larger question, and it remains unanswered using this type of comparison, is whether the business strategy underpinning the Canadian petrochemical industry — the commodity chemicals orientation — is really the optimal approach. That is the real issue. It is a critical question, and one that must be answered in terms of each company's particular set of circumstances. We therefore turn to a review of the most important Canadian petrochemical companies.

Major Canadian Petrochemical Companies

The major petrochemical companies in Canada, and their 1989 sales, are listed in Table 9. Although Nova Petrochemicals, the largest, is Canadian owned, most of the other large companies are subsidiaries of foreign multinationals. In addition, there are a number of nonchemical companies that conduct a major part of their business in petrochemicals.

Nova Petrochemicals

During the 15 years since the mid-1970s, Nova has built a Canadian-owned and -controlled chemical company that is now the largest in Canada. It has world-scale chemical facilities in Alberta and Ontario; world-scale plastics facilities in Canada and the United States; and worldwide independent marketing and distribution capabilities. It has steadily developed its R&D capabilities in both Canada and the United States, with a budget of $34 million and a scientific staff of 300 employees.

Nova has its major operations in Alberta. The corporation produces ethylene, low- and high-density polyethylene, polypropylene, ethylbenzene, styrene, polystyrene, and methanol. In 1988, Nova acquired Polysar in Sarnia; in 1990, however, it sold the rubber division to reduce debt load.

Nova has two R&D centres — one in Calgary, the other in Boston — each of which supports a portion of the company's polymer business. The centre in Calgary, with a staff of between 100 and 150, supports the company's polyethylene and polypropylene businesses; the Boston centre, which is about the same size, provides technical support to the various polystyrene plants in North America. (The former Polysar centre, now taken over by Bayer, continues to provide support to the rubber business.) Nova uses its internal resources for most of its R&D activities; it does, however, contract out some research to universities and research institutes.

Table 9. Major petrochemical producers in Canada

Chemical companies	Ownership	1989 sales ($ millions)
Nova Petrochemicals	Canadian	2 551
Dow Chemical Canada	U.S.	2 078
Du Pont Canada	U.S.	1 435
CIL/ICI Canada	British	1 206
Esso Chemical Canada	U.S.	920
Shell Canada Chemical	Dutch	740
Union Carbide Canada	U.S.	560
Monsanto Canada	U.S.	490
Celanese Canada	U.S.	410
B.F. Goodrich Canada	U.S.	390
Hoechst Canada	German	294
AT Plastics	Canadian	190
Ocelot Industries	Canadian	174
Kemtec Petrochemical	Canadian	158
Nonchemical companies with major petrochemical production		
General Electric Canada	U.S.	1 612
Canadian Occidental	U.S.	591
PPG Canada	U.S.	553
BASF Canada	German	394

Source: Law, Sigurdson and Associates, "Analysis of Technology Adoption and R&D Activity among Canadian Petrochemical Firms," contract report prepared for Science Council of Canada, 1990 (unpublished), II-10.

Although it is Canadian owned, Nova's technology strategy does not differ significantly from that of the Canadian subsidiaries of foreign multinationals. Basically, Nova uses an adopt and adapt strategy to support the production of commodity chemicals. The corporation has been successful in efficiently and competitively manufacturing and selling a broad range of basic chemicals and plastics.

As Canada's largest petrochemical producer, Nova is not seeking more aggressive and innovative business and technology strategies than it has at present. Nova seems large enough to achieve economies of scale; it also has low-cost feedstocks. But Nova's technology is not significantly different from that of other petrochemical producers. It has grown by following an aggressive business strategy based on using the best available technology.

Dow Chemical Canada

The R&D facility of Dow Chemical Canada at Sarnia employs a staff of about 100. The company can also draw upon the worldwide R&D facilities of its parent company, which has its major research centre about 60 miles from Sarnia in the United States.

In Canada, Dow conducts research and provides technical support to the polyethylene and polystyrene businesses. Although Dow Chemical Canada obtains basic plant technology from the parent company, it has a mandate to conduct process modifications and development on polyethylene resins. Dow also conducts work on styrene and polystyrene resins.

Du Pont Canada

Du Pont has about 180 staff at its research centre at Kingston. Activities at the centre include technical development and technology transfer from the parent company and other chemical companies.

The organization of Du Pont Canada with regard to research is somewhat noteworthy, for it is Du Pont's Canadian management that, in essence, decides the amount of local research to be done. Many multinationals do not decentralize the R&D function in this way. Nevertheless, a multinational firm can gain a competitive edge with a decentralization that capitalizes on creative local science and engineering. (See Science Council of Canada Sectoral Technology Strategy Series, No. 4: *The Canadian Automotive-Vehicle Sector*, for further discussion of R&D decentralization.)

The major activities of the Du Pont Canada centre support the company's polyethylene and nylon businesses. It has developed a linear polyethylene production process, based on the solution polymerization technology of its parent company, E.I. du Pont. The Canadian company continues to support and further adapt the technology, which has been successfully licensed around the world.

Although the basic nylon process technology found in Du Pont's Maitland, Ontario, plant was obtained from its parent firm, Du Pont Canada has been active in the development of nylon technology; it also developed the cyclohexane oxidation process for making one of the raw materials of nylon, as well as nylon film technology. The Canadian company has a mandate to develop new nylon polymers.

ICI Canada

The main products of ICI in Canada are ammonia, urea, and ammonium nitrate — all of which are used in fertilizers and explosives. Although ICI Canada conducts some applied research in Canada, most of its technology comes from its parent company in Britain.

Esso Chemical Canada

Esso's technical centre in Sarnia, with a staff of approximately 60, supports the company's business in several areas: polymers (polyethylene and polyvinyl chloride), basic chemicals (ethylene and BTX, solvents), and performance products (specialty and pulp and paper chemicals). The company also conducts development work on fertilizers in Redwater, Alberta.

The technical centre provides both process and product development support for the company's polyethylene and polyvinyl chloride resins. The Canadian company relies on its parent organization for basic research needs.

Shell Canada Chemical

Shell Canada produces ethylbenzene, styrene, polypropylene, and isopropyl alcohol in Canada. The company's research centre at Oakville provides research and technical support for its Canadian production plants. Most of the company's R&D in Canada is in polypropylene resins. Shell Canada also has access to the R&D of its parent organization.

University Petrochemical R&D

Although the bulk of R&D in the petrochemical sector in Canada, as in the rest of the world, is financed and conducted by the industry itself, the major companies provide financial support for university research, and some companies work with provincial research organizations and the National Research Council of Canada. Canadian universities that conduct research in petrochemicals include McGill University, McMaster University, Technical University of Nova Scotia, École polytechnique, Queen's University, Université du Québec à Trois-Rivières, University of Toronto, and University of Waterloo.

Initiatives have been taken, in part under the auspices of the Canadian Chemical Producers' Association, to improve cooperation and coordination between the universities and the industry. Mention should also be made of the Institute for Chemical Science and Technology, which is supported by both the industry and the universities.

Opportunities and Growth Strategies for the Canadian Petrochemical Sector

The major competitive strength of the Canadian petrochemical sector lies in its abundant supplies of natural gas and crude oil from which feedstocks are derived. Based on these supplies, the capital investment in petrochemicals in Canada has been considerable. The Canadian sector is profitable and has been successful overall.

However, to be competitive in world commodity chemical markets, a country has to keep producing and selling at lower prices than its competitors. Achieving economies of scale in commodity petrochemical production requires considerable capital investment in the latest technology, in addition to low-cost oil and gas feedstocks. A country's investment climate and tax structure are therefore crucial; indeed, they can help to make or break the industry. However, in the 1980s, the National Energy Program of the Canadian government placed an extra tax burden on Canadian producers, thereby reducing their competitiveness. Although the Free Trade Agreement with the United States may well benefit the commodity petrochemical sector, enabling access to larger markets, a high real cost of capital will deter major investment.

Most Canadian companies conduct some process development work, but their investment in R&D has been much less than that of their parent firms abroad. Most of the technology in Canadian plants is developed by parent companies or licensed from machinery or major petrochemical firms. Thus the Canadian companies have access to the latest available technology and process improvements. But Canada is left without the technological base on which to build broader innovation and remains dependent on external technology.

Questioning Canada's Commodity Orientation

To conclude that commodity petrochemicals are "bad" and specialty chemicals are "good" is inadvisable at this point. Indeed, many commercial factors support the continued Canadian production of commodity petrochemicals. Nevertheless, questions should be raised about Canada's commodity orientation. They are listed below.

- The Canadian sector is economically efficient. But will it be able to grow in the long run only by the sacrifice of Canadian natural gas rents?

- The Canadian sector currently has access to world-class technology through linkages to U.S. and European parent companies. But if new world-class technology comes from elsewhere (for example, from Japan), will the Canadian sector find it as easy to obtain?

- The Canadian sector has generally been termed "low R&D-intensive," reflecting its commodity orientation. But will the world trend in chemical technology change? Will it begin to emphasize product development and systems integration capabilities, rather than scale economies?

- The Canadian sector has avoided marketing costs (and hence gained efficiency) by selling commodities to a limited range of customers. But does that practice not leave the industry vulnerable to potential changes in end-product specifications that could obviate Canadian investments to a large extent?

- The Canadian sector has had competitive or low-cost feedstocks until now. But will its management have the authority and strength to focus investments in Mexico, or some other region if necessary, to obtain still lower-cost feedstocks?

Options for Future Growth

More Product Mandates

Many Canadian companies work with customers to develop chemicals and resins for specific end-use applications. In the past, one of the drawbacks of this type of work was Canada's small market size. However, thanks to the Canada-U.S. Free Trade Agreement, Canadian subsidiaries of multinational companies should have access to world markets for their products in the future. Some Canadian companies already have product mandates for specific areas. Canadian managers should make the earning of more product mandates a priority.

Marketing

From their survey of Canadian petrochemical companies, Law, Sigurdson and Associates concluded that, while there may be great potential for innovation in both process and market applications, there is little incentive to innovate in Canada. They found that many petrochemical companies simply do not have the critical mass to develop new technology. Moreover, with the relatively small Canadian market, the risk/reward ratio for innovation is too high for most Canadian-owned chemical firm executives. As well, although the Canada-U.S. Free Trade Agreement holds promise for Canada's access to the much larger North American market, the additional problem arises of putting into place the necessary marketing network. Trade associations may have a useful role to play in establishing such a network.

Environmental Regulation

A major concern of the petrochemical industry is environmental regulation. Less stringent environmental regulations in some developing countries could make sites there more attractive for future development, at Canada's expense. However, the Canadian industry is not against environmental regulation. Rather, because of the long lead times inherent in the building of large-scale plants, the industry needs to have a stable regulatory environment to facilitate intelligent planning.

Integrating the Production Cycle

Although the specialty chemicals sector is less capital-intensive than the commodities sector, the past decade has seen a decline in Canada's output and competitiveness in specialty chemicals, due in part to the removal of tariff barriers. Many Canadian producers were simply too small in the past to compete against U.S. producers in North American markets. Opportunities for long-term payoffs in developing the specialty chemical industry may still be available. The key challenge is to develop a more sophisticated integration of the whole production cycle, from raw materials to finished products. This will mean closer cooperation with client, or downstream, industries, to understand their market needs.

For example, Canada's large pulp and paper sector has come under increased pressure to reduce pollutants in its effluents. Research into the development of synthetic flocculants and resins, for use in improving the removal of contaminants in water treatment units, is under way. But researchers must work closely with the pulp and paper companies if they are to develop the chemicals and reactor conditions needed to maximize the effectiveness of the treatment process. Other industries have unique needs as well, such as automotive parts; mining and mineral processing; iron and steel; nonferrous

metals; agriculture and food processing; even electronics. Developing products in conjunction with the industries concerned to improve, in turn, the quality of their products and services could lead to major Canadian export opportunities.

Industry, Science and Technology Canada, through its market intelligence services, has made considerable progress in identifying niche areas for specialty chemical development. It has concluded that important opportunities exist. Some of the smaller Canadian players, in particular, might benefit from this effort.

The Challenges Ahead

Among the challenges the global chemical industry must face in the next decade are the problems inherent in environmental pollution, the reduction of which will require considerable investment in process R&D (to reduce pollutants), as well as product R&D (to find replacements for hazardous chemicals and ways of recycling plastics). There are also pressures for short-term performance in an industry with high capital requirements for research and for large facilities, both of which have long-term payoffs. The industry will have to deal with trade issues, including protectionism, free trade agreements in both North America and Europe, and fluctuating exchange rates, and will have to reckon with unpredictable oil prices and overcapacity. However, there are possible growth opportunities in polymers, intermediate chemicals, and the chemicals used in small, niche markets such as the high-tech industry. Some commentators forecast an even greater shift to specialty chemicals, concluding that product differentiation will be important for company growth.

In the long run, any strategy of product differentiation will require Canada's petrochemical companies to work more closely with end-use customers and to pursue a downstream integration strategy. There are opportunities, especially for polymer and resin producers, to integrate downstream and to work with end-use customers in developing both products and processes. When contemplating downstream integration, however, Canadian companies must consider the size of the Canadian market, Canada's improved accessibility to the American market, and their own ability to earn product mandates from parent organizations. Product differentiation will not be easy. With its commodity-process orientation, the industry has had only limited experience with new product R&D in recent years. Clearly, it will be a challenge to develop or re-acquire that capability. Despite low-cost feedstocks and world-scale operations, the Canadian petrochemical industry must add innovative new product capabilities if it is to reach its real potential in the years ahead.

Appendix: Framework for Technology Strategies

As part of the methodology for analysing each sector, the Science Council of Canada sought whenever possible to assess company technology strategies according to the following framework:

	adopt and adapt	innovation	breakthrough
product			
process			

Strategy Classes

Adopt and Adapt: Acquire a technology and adapt it to serve as a competitive platform.

Innovation: Incrementally improve on winning technology to get greater market share or maintain competitive edge.

Breakthrough: Seek to create a discontinuity in the marketplace, thereby leaping ahead of the competition.

The company case studies generally looked for at least seven key dynamics influencing a company's technology strategy:

- three internal dynamics:
  - competitive position,
  - capacity for innovation, and
  - strategy and vision; and
- four external dynamics:
  - customer demands,
  - competitive rivalry,
  - supply condition, and
  - available technology.

The methodology also incorporated essentially a three-step process for each sector. In the first step one or more contractors analysed the main elements in the competitive and R&D performance of the Canadian sector and its leading foreign competitors. The second step included evaluation of the contract report(s), discussion with contractors and other experts, additional in-house research, and preparation of a draft Council report. In the third step, external reviewers commented on one or more drafts of the Council report, which were then revised and refined as required, drawing on the advice of the liaison person for that sector on the project committee (see Acknowledgements). For some sectors, the third step also involved several external reviewers in a small workshop, one part of which helped

define some elements of a potential action plan for the sector. The report was then submitted for final approval to the Executive Committee of the Science Council, before being forwarded to Industry, Science and Technology Canada.

Notes

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2. "Shake, heat, squeaky-pop," *The Economist*, 16 July 1988, 68-69.

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